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Strangeness Production at RHIC

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The STAR experiment at RHIC was designed to identify a wide range of strange particles at mid-rapidity. With only $\sim 300,000$ central events it has already been possible to cleanly identify charged and neutral kaons, Λ s, Ξ s, Ω s, and their respective anti-particles plus the ϕ and K^* resonances. Presented here are preliminary results for strange particle ratios and spectra of charged kaons from Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV.

1. Introduction

The STAR detector is one of the four experiments designed to measure Au-Au collisions at the newly operational RHIC accelerator at the Brookhaven National Laboratory. Amongst these experiments STAR stands out as being capable of measuring a wide spectrum of strange particles produced in these collisions. The main tracking detector, a TPC, provides a wide, symmetrical, acceptance for charged particles around mid-rapidity.

Strangeness production has long been suggested as a probe of the central fireball region due to the possibility of unique production mechanisms should a QGP be formed. Multi-strange anti-baryon production is of particular interest due to the large energy required to create these particles via standard hadron-hadron collisions. Indeed, the recent CERN announcement of the possible observation of a new form of matter in the SPS Pb-Pb collisions [1] pointed to the observed enhancement of strangeness production over p-A collisions.

Strangeness production can be used as a probe in many ways. The first is simply by measuring the various strange particle yields and thus determining the chemical content of the fireball. The most useful particles to measure for this procedure are the kaons as they carry $\sim 70\%$ of the strange quarks. A study of strange resonance production can be used as a “clock” to ascertain when strangeness production occurs. The thermal freezeout parameters of strange particles may be studied by measuring their HBT radii and momentum spectra. Those particles with a smaller interaction cross section freezeout earlier and therefore probe an earlier time in the evolution of the system. In this area of particular interest are the ϕ and Ω particles which have shown indications of different transverse flow properties in the SPS results [2–4]. STAR’s large acceptance and the higher collision energies mean the raw reconstructed yields per event of kaons and Λ are high, ~ 1 per event at present which is expected to increase when RHIC reaches its top collision energies next run. This opens the door to making K_s^0 and Λ HBT measurements that have only been tentatively explored previously due to extremely poor statistics.

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Studies of various particle ratios allow the chemical freezeout conditions to be explored and the ratios of anti-baryon to baryon provide information on the baryon content in the central region. Finally, strange particles can be used in a flow analysis to study various aspects of flow, such as the sensitivity of different particle species to the flow and possibly to help determine when flow sets in.

2. Analysis

The STAR experiment has been described in detail elsewhere in these proceedings [5,6]. Here the main facts that are of particular importance for the strangeness measurements will be reiterated.

The results presented are from data recorded during the Summer 2000 Au-Au collisions at $\sqrt{s_{NN}} = 130$ GeV and are taken from 300,000 central events and 160,000 min bias events, where central is defined as the top 7% of the measured charged multiplicity. For this data taking period the STAR magnetic field was 0.25 T, which is half its nominal value. This means that the momentum resolution is slightly worse at high momentum than originally planned for the FY200 run but also that the acceptance at lower p_t is increased. With the inner radius of the TPC being 50 cm the detector has an acceptance for charged particles with $p_t > 75$ MeV/c. Its 4 m length means that there is also acceptance out to $-1.8 < \eta < 1.8$.

Strange particles are identified in three distinct manners, the first being via the specific ionization of the TPC gas by charged particles. This allows STAR to identify charged kaons up to a total momentum of 700 MeV/c with good precision and purity.

The second technique is via the topological identification of neutral, and charged, particle decays. The parent particle decays with a distinctive pattern that can be easily reconstructed, and via a series of geometrical cuts a good signal to noise ratio of the reconstructed parent can be obtained (see for example Fig. 5 and Fig. 6). In this way neutral particles, such as the K_s^0 and Λ can be reconstructed by measuring their charged daughter decay modes. By identifying the “kink” decay of the charged kaon ($K \rightarrow \mu + \nu$ and $K \rightarrow \pi + \pi^0$) the charged kaon measurement can be extended to high momenta where the dE/dx measurement no longer has any resolving power. The more complicated “cascade” decay schema of the Ξ and Ω can also be reconstructed by a series of topological pattern recognitions.

Short-lived resonances can also be reconstructed in STAR using a mixed event background technique. The present status of the resonance analysis is discussed elsewhere in these proceedings [7].

3. Kaon Spectra

As kaons carry a significant fraction of the strange quarks created in heavy ion collisions, their measurement gives a good indication of how much strangeness is produced.

Fig. 1 shows typical m_t spectra for positively and negatively charged kaons identified via the kink method for the 7% most central events. They can be well represented by an exponential distribution as indicated by the solid lines. The mid-rapidity inverse slopes obtained are $272 \pm 5(stat) \pm 10(sys)$ MeV for K^- and $267 \pm 5(stat) \pm 10(sys)$ MeV for K^+ . Fig. 2 shows that the K^- inverse slopes increase with multiplicity and then saturate

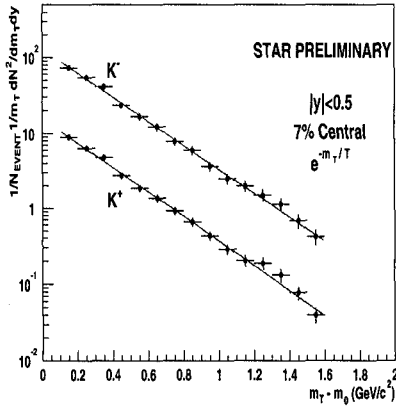


Figure 1. K^+ and K^- m_t spectra. The data are from the kink analysis. The K^- data has been scaled by 10 for clarity.

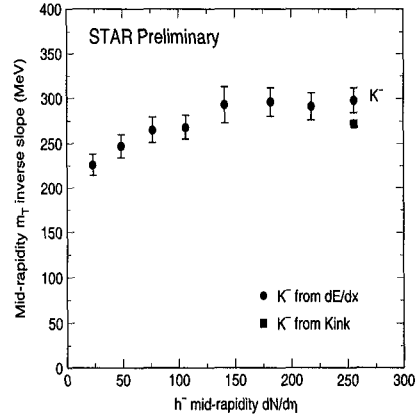


Figure 2. K^- fitted inverse slopes as a function of mid-rapidity negatively charged particles.

at ~ 300 MeV for the most central events. This plot also shows that the charged kaon results from the two independent measurements are in good agreement as are the inverse slope fits of the K^+ and K^- . A summary of the inverse slopes measured by STAR for central events is shown in Fig. 3. The line indicates the trend of the SPS data, from which it has been calculated that there is an average transverse flow of $\beta = 0.4 - 0.5$, and the hollow points are the NA44/NA49 results for those particles measured by STAR. There is an indication of an increase in transverse flow at RHIC compared to the SPS and that the light strange mesons seem to feel the same magnitude of flow as the protons and pions.

The rapidity distribution for the negative kaons is shown in Fig. 4. The measured data cover nearly 90% of the p_t spectrum and hence the error introduced via the extrapolation to full phase space is small. The mid rapidity yield for central events from the kink analysis is $35 \pm 3(stat) \pm 5(sys)$ for K^+ and $30 \pm 3(stat) \pm 4(sys)$ for K^- . For comparison the K^- mid-rapidity yield from the dE/dx analysis is $38 \pm 2(stat) \pm 8(sys)$.

4. Particle Ratios

Fig. 5 and Fig. 6 show the invariant mass distributions for Ξ^- s, $\bar{\Xi}^+$ s and the sum of $\Omega^- + \bar{\Omega}^+$. It can be seen in all cases that there is an excellent signal to noise ratio and that the mass resolution is ~ 6 MeV/ c^2 .

Although the reconstruction corrections for many of the identified particles are not yet complete, the symmetry of the STAR detector allows us to investigate the anti-particle to particle ratios since any efficiency corrections should cancel. Fig. 7 shows the $\bar{\Lambda}/\Lambda$ ratio as a function of p_t for central events, the error bars shown are statistical. Our acceptance and reconstruction efficiency are poor at low momentum which is suspected to be the cause

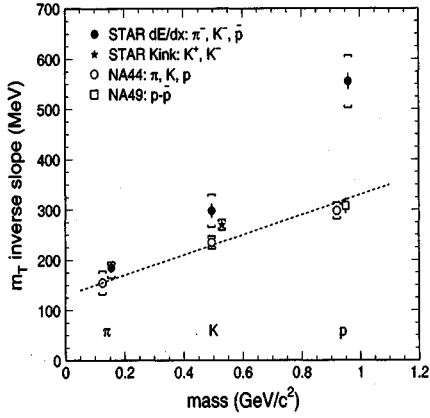


Figure 3. Fitted inverse slope values versus particle mass for central Au-Au collisions. The line indicates the trend of the SPS data.

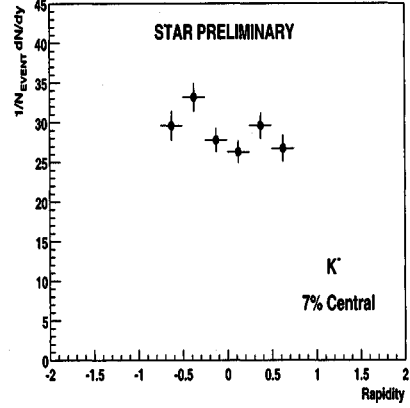


Figure 4. K^- rapidity spectrum from central events via kink identification.

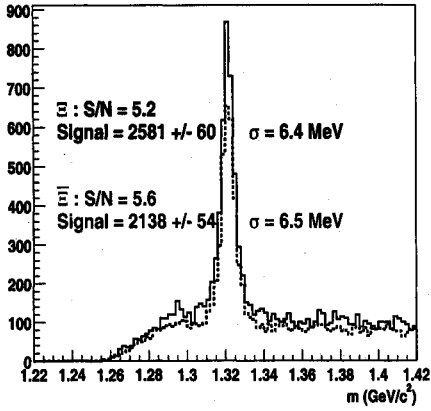


Figure 5. Invariant Mass distribution for (solid line) Ξ^- and (dashed line) Ξ^+ .

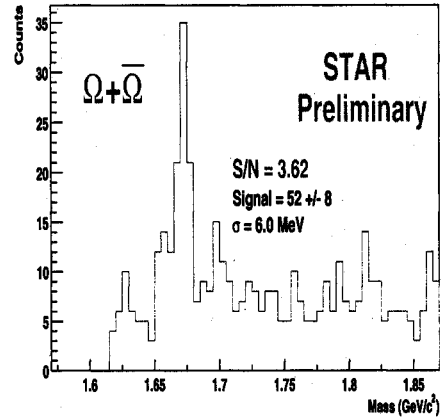


Figure 6. Invariant Mass distribution for the sum of $\Omega^- + \bar{\Omega}^+$.

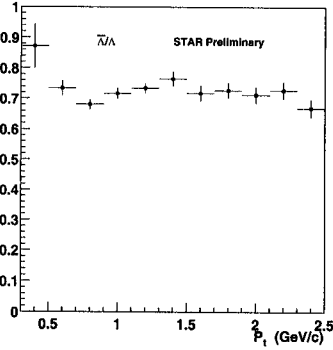


Figure 7. $\bar{\Lambda}/\Lambda$ ratio as a function of p_t for central events, $-0.5 < y < 0.5$.

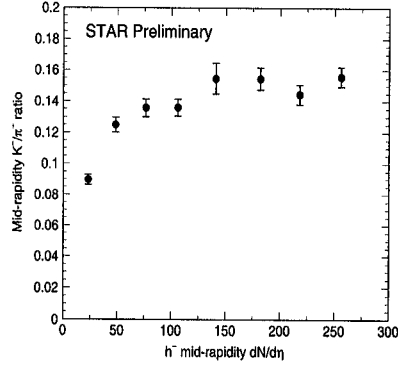


Figure 8. K^-/π^- ratio as a function of mid-rapidity negative particles.

of the deviation from a flat line in the lowest p_t bin. This ratio is flat indicating that the momentum spectra of these two particles are identical over the region covered. The mean $\bar{\Lambda}/\Lambda$ value is $0.73 \pm 0.03(stat)$ while the $\bar{\Xi}^+/\Xi$ ratio is $0.82 \pm 0.08(stat)$ and that of the \bar{p}/p ratio is $0.6 \pm 0.02(stat) \pm 0.06(sys)$ for central collisions [8]. Corrections have been made to the \bar{p}/p and $\bar{\Lambda}/\Lambda$ ratio to account for the differing annihilation cross-sections of the anti-baryon to the baryon. As yet no feed-down correction has been applied but this should be small as the Λ and Ξ ratios are near one. The fact that the mid-rapidity anti-baryon to baryon ratio is less than unity in all cases can be taken as an indication that the central collision region is not baryon free. It can be seen from Fig. 9 that the degree of stopping, or baryon number transport processes, at the SPS is more significant than at RHIC. See [9] for further discussion of this topic.

The K^+/K^- ratio, not shown, is flat at $1.08 \pm 0.01(stat) \pm 0.06(sys)$ (this is based on the identification of kaons by dE/dx measurement, the results from the kink analysis are systematically higher at $1.14 \pm 0.02(stat) \pm 0.06(sys)$) as a function of centrality. The K^+/K^- ratio is another measurement of the baryon density and again indicates that the central region is approaching, but is not yet, baryon free. The K^-/π^- ratio as a function of mid-rapidity negative particles is shown in Fig. 8. The K^-/π^- ratio increases by nearly a factor of two from peripheral to most central collisions with a sharp rise at the most peripheral region.

Fig. 9 shows a summary of all the particle ratios currently reported by STAR. It can be seen that RHIC collisions are apparently closer to being transparent than SPS collisions but that the strangeness chemical content is not that different from the SPS.

5. Conclusions

Although the analysis of the STAR data has only just begun it has already produced a wealth of information about the strangeness content of Au-Au collisions at $\sqrt{s_{NN}} = 130$

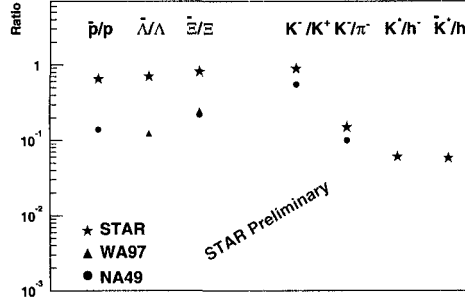


Figure 9. Particle ratio summary and comparison to SPS

GeV. The quality and quantity of the data taken during this first running period is sufficient to allow us to obtain spectra for K_s^0 , Λ , $\bar{\Lambda}$, Ξ , $\bar{\Xi}$, ϕ and important preliminary estimates for the yields of Ω , $\bar{\Omega}$, K^* and \bar{K}^* .

It has been shown that the kaons fit a thermal distribution and appear to experience the same high transverse flow as protons and pions. Also the ratio of anti-baryons/baryons shows that the collisions, while not quite transparent, indicate a lower baryon content at mid-rapidity than at the SPS. All ratios show no large trends as a function of rapidity or p_t . With respect to the anti-particle to particle ratios as a function of p_t , this means that both particles freezeout with the same apparent temperature. The K^-/π^- ratio, however, increases by a factor of two from most peripheral to central events possibly indicating an increase in strangeness production relative to light quark production as the collisions become more violent.

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